Ultra-Thin Whitetopping in India: State-of- Practice

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Abstract—**Ultra-Thin Whitetopping (UTW) is a technology to construct 50-100mm thick cement concrete overlay on distressed asphalt pavement as a rehabilitation technique. There have been several UTW projects completed in India, the first in Pune, subsequently in New Delhi, Ghaziabad, Mumbai, and Thane. All projects have shown good to excellent performance so far, indicating that this rehabilitation strategy can stand up to the Indian climate and traffic conditions. The suitability of UTW rehabilitation for a particular site is dependent on several factors including existing asphalt thickness, volume of truck traffic, base and subgrade support, and pavement conditions. This paper outlines the state-of-practice in India for construction of UTW considering mix traffic, extreme climatic conditions, use of indigenous materials and design aspects as per Indian Road Congress (IRC) guidelines.**

Index Terms— **Deflection, Hot Mix Asphalt, Stress, Ultra- Thin Whitetopping**

I. Introduction

The increasing truck weights and tyre pressures on our pavements in recent years have pushed the demand on the performance of our pavements to a higher level. Many asphalt pavements have experienced rutting while many others have experienced longitudinal cracking. One of the possible solutions to this problem is the use of whitetopping (WT), which is a cement concrete layer placed over an existing asphalt pavement. Whitetopping is stronger than asphalt overlay, and thus more resistant to rutting and surface-initiated cracking. Consequently, whitetopping pavements pose potential economical and technical benefits. However, they need to be effectively evaluated for feasibility and proper application techniques, suitable for India, so that their use can provide the maximum benefits to the road users in particular and Indian economy at large.

Ultra-thin whitetopping is one of the types of whitetopping in which a thin layer of concrete varying from 50 to 100mm thick with fibers is placed over a prepared surface of distressed asphalt pavement. In addition to the thickness of the concrete overlay, other factors differentiate UTW from conventional concrete overlays are: (a) a substantial degree of bond between the concrete overlay and the prepared asphalt surface, and (b) much closer joint spacing.

Ultra-Thin Whitetopping is an emerging and innovative technology for asphalt pavement rehabilitation in India.The concrete overlay utilizes closely spaced transverse and longitudinal jointsto reduce tensile stresses caused by traffic loads and environmental conditions such as thermal stresses and curling due to temperature changes. Concrete with fibers as reinforcement improves its load carrying capacity, durability, and shrinkage cracking resistance.

Design procedure for UTW is similar to those of conventional concrete pavement design. In this study, design of UTW has been carried out as per IRC 58:2002 guidelines and IRC: SP: 76-2008 for a cluster of roads in Dahanukar Colony Pune, Maharashtra State. These residential streets earlier constructed with HMA are subjected to medium traffic flow and commercial vehicles, due to which they got deteriorated and need rehabilitation. It was decided by Pune Municipal Corporation to upgrade and improve these roads with UTW overlay. One of the roads with 1.00 km length, 125 mm thickness and 7.5 m carriageway from these is taken for this study.

II. Historical Perspective

According to National Cooperative Highway Research Program (NCHRP) Synthesis of Highway Practice 99, the first recorded use of whitetopping in the United States was in Terre Haute, Indiana. On this project, constructed in 1918, a 75 to 100mm jointed reinforced concrete overlay was put in place. Between that time and 1992, approximately 200 whitetopping projects had been documented; of which 158 have been jointed plain concrete pavement, 14 continuously reinforced concrete pavement, 10 FRC, and 7 jointed reinforced concrete pavement [1].

Since 1992, the ACPA has been tracking the use of UTW in the United States and it has documented more than 300 projects during this 10 year period [2]. The first examples of modern UTW construction were cited in Europe, specifically in Belgium and Sweden. Other countries reporting recent projects include Canada, Mexico,Brazil, Republic of (South) Korea, Japan, France, Austria, and Netherlands [3]. Ultra-thin whitetopping overlay technology has been started in India in 2003. Table I show various UTW projects have been constructed in India till 2009 [4].

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TABLE I. Utw overlay projects in India

Year	Location	Thickness (mm)
2003	Pune (In front of P.M.C. Office)	125
2004	New Delhi (CRRI campus road)	40-75
2006	New Delhi (Moolchanel and Prembari under pass)	125
2006	Ghaziabad (Campune road of HRD centre)	50
2006	New Delhi (NDMC office campus road at Parliament Street)	100
2006	New Delhi (Meetha Pur, Badarpur)	125
2007	Mumbai(Mahul Road)	100
2008	Thane (In Gaothan area)	125
2009	Pune(Dahanukar Colony, Kothrud)	125

III. Design Procedure

The design principal adopted for UTW is similar to those of normal concrete pavement as provided in IRC:58:2002[5] and IRC: 15 – 2002 [6]. These standards are followed for design of UTW except determination of Modulus of Subgrade Reaction (k). The traffic data and other basic data is collected for the design of UTW and stepwise design procedure is given below:

A. Traffic Data Collection and Analysis

Traffic data in terms of commercial vehicles per day (CVPD) is collected for three days during various time periods in a day and shown in Table II. For design 7.5% (r) of growth rate is considered and design period is assumed as 20 years (n). Design traffic in terms of cumulative repetition of axles has been computed as 4248708 commercial vehicles from the following formula [5]:

Design traffic in terms of Cumulative repetition

$$C = \frac{365 * A\left\{(1+r)^n - 1\right\}}{r} \quad (1)$$

Design traffic = 25% of the total repetition of commercial vehicles = 1062177

TABLE II. Traffic data in terms of commercial vehicles per day (cvpd)

Commercial vehicles (mini bus, standard bus, trucks)			Total
Date: 5/5/2009	6/5/2009	7/5/2009	(A)
73	38	81	192

B. Calculation for Modulus of Subgrade Reaction (k)

Modulus of subgrade reaction (k-value) has been determined by conducting Benkelman Beam Deflection (BBD) on the surface of Hot Mix Asphalt (HMA). The maximum value of deflection obtained from BBD has been used to find out k-value from the graph shown in Figure 1.Four days soaked California Bearing Ratio (CBR) value of the subgrade soil has been determined and IRC: 58-2002 [5] has been used for finding out k-value corresponding to this CBR value. Minimum k-value obtained by these two methods has been used for the design of UTW.

C. k-value from Benkelman Beam Deflection (BBD)

BBD test has been conducted as per IRC: 81–1997 guidelines on three locations as shown in Table III [7]. Maximum deflection of location no. 2 from BBD data is 2.10 mm and corresponding k-value is 0.03714 MPa/mm as obtained from Figure 1 given by Corporation of Engineers and Portland Cement Association (PCA).

TABLE III. Deflection data

Sr. No.	Location	Deflection (mm)
1	Road No.1	1.94
2	Road No2	2.10
3	Road No.3	2.08

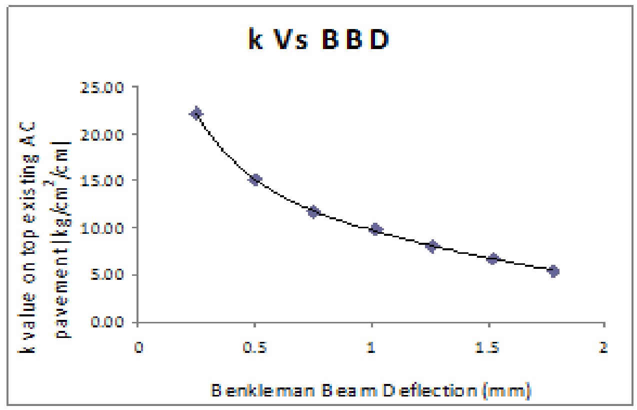

Figure 1. Relation between BBD and k-value
[Source: Corporation of Engineers and PCA]

D. k-value from California Bearing Ratio

Laboratory soaked CBR test for 4 days has been conducted on undisturbed sample of subgrade soil and 20.03 % CBR value is obtained. From Table 2 given in IRC:58:2002, k-value corresponding to 20.3% of CBR is 0.096 MPa/mm. Modified k-value based on equivalent granular thickness of 375mm is 0.2810 MPa/mm which is obtained by using Figure 2 and shown in Table IV.

TABLE IV. Modified k value as per existing thickness of bituminous pavement

Subgrade Modulus	Existing Pavement Thickness (Bituminous surface + Base) in mm				
	100	150	250	300	**375**
1.4	2.1	2.4	3.3	4.7	**6.6**
2.8	3.9	4.4	5.8	7.8	**11.1**
5.6	6.4	7.5	9.7	14.1	**18.1**
8.4	9.1	10.2	12.7	16.6	**24.7**
9.6	**10.1**	**11.1**	**13.6**	**17.1**	**28.1**

Minimum value of modulus of subgrade reaction (k-value) obtained from Benkelman Beam Deflection test and California Bearing Ratio test is 0.03714 MPa/mm. and same is used for further design of UTW.

E. Fatigue Behaviour of UTW

Due to repeated application of flexural stresses by traffic load, progressive fatigue damage takes place in the cement concrete in the form of micro cracks. Trial thickness assumed for design of cement concrete layer is 125 mm. The total fatigue life consumed is 18.738%, which is less than 100 %; therefore design is safe from fatigue life consideration. Hence final thickness of cement concrete to be adopted is 125 mm.

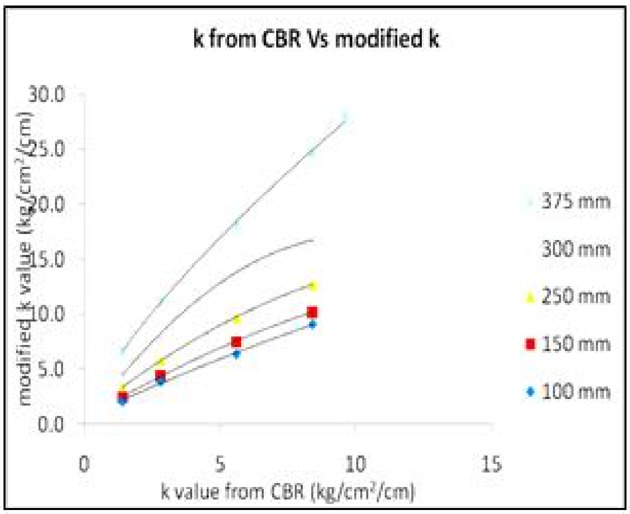

Figure 2. Extrapolated graph for 375mm thickness

IV. Calculations of Stresses

The factors considered for design of pavement thickness are; flexural stresses due traffic loads and temperature differentials between top and bottom fibers of the cement concrete slab. The cross section of UTW overlay has been shown in Figure 3.

A. Stresses due to Temperature Differential in Edge Region

Temperature stresses at critical edge region (S_{te}) have been calculated as per Westergaard analysis [8] using Bradbury's coefficient using the following equation [5]:

$$S_{te} = \frac{E\,\alpha\,\Delta t\,C}{2} \qquad (2)$$

Where,
E = elastic modulus of concrete = 3 x 10^5 N/mm^2
α = coefficient of thermal expansion =10x10^{-6} per ^{0}C (IRC-58 clause no 4.7.3) [5]
Δt = temperature differential (as per IRC-58 Table-1) [5]
C= Bradbury coefficient depend on aspect ratio of slab
L=joint spacing as 1000 mm i.e. each panel as square
l= radius of relative stiffness

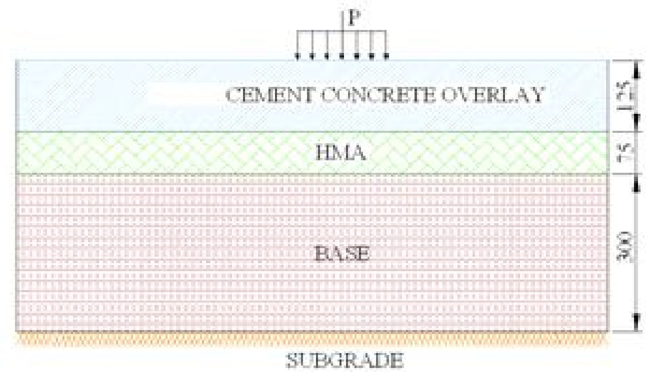

Figure 3. Cross section of UTW overlay

$$l = \sqrt[4]{\frac{Eh^3}{12\left(1-\mu^2\right)k}} \qquad (3)$$

Where,
h = pavement thickness, mm
μ = Poisson's ratio for concrete= 0.15
(as per IRC-58, clause no. 4.7.2 [5]
k = modulus of subgrade reaction MPa/mm
L/l (aspect ratio) = 100/ 69.433 = 1.440, form Bradbury chart for aspect ratio 1.440 the coefficient C by interpolation is 0.018

The temperature differential for Pune, (Maharashtra State) and as per thickness of slab which is 125 mm the temperature differential is taken as 17.3 [5], therefore,
Temperature stresses = 0.0467 MPa

B. Wheel Load Stresses in Edge Region

The load stresses at critical edge region have been calculated as per Westergaard analysis modified by Teller and Sutherland using the following equation [6] and results has been given in Table V.

$$\sigma_e = 0.529\frac{P}{h^2}(1+0.54\mu)\left(4\log_{10}\frac{l}{b}+\log_{10}b-0.4048\right) \quad \text{..........} \quad (4)$$

Where,
P = design wheel load, kN = half of the single axle load= 80kN
l = radios of relative stiffness, mm =694.33mm
a= Radius of load contact areas, (assumed circular)
b= Radius of equivalent distribution of pressure, cm

Since, Westergaard formula is only for circular loading therefore for dual wheel load 'a' is calculated in terms of equivalent circular area.

$$a = \left[0.8521 \times \frac{P}{q\pi} + \frac{S}{\pi}\left(\frac{P}{0.5227 \times q}\right)^{0.5}\right]^{0.5} \qquad (5)$$

Where, b = a, for a/h > 1.724

and $b = \left(1.6a^2 + h^2\right)^{0.5} - 0.675\,h$

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Since a/h=1.768 > 1.724, therefore b = a
Total flexural stress = stress due to temperature differential+ stress due to wheel load
= 5.101MPa < 6.75 MPa
(MR = 6.75 MPa for center point loading)

C. Corner Stresses Due to Wheel Load Stress

The load stresses at corner region (S_c) have been calculated as per Westergaard analysis [8] modified by Kelly using the following equation [5]:

$$\sigma = \frac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{1.2}\right] \qquad (6)$$

TABLE V. Wheel load stresses in concrete overlay slab

Sr. No.	Loading positions	Stress in concrete overlay slab
1	Edge	5.055 MPa
2	Corner	6.023 MPa

V. Concrete Mix Design

The type of concrete mix for a particular UTW project has been selected on the basis of traffic conditions, desired concrete strength and opening to traffic. In this project M40 grade of concrete along with polypropylene fibers has been used for UTW overlay by carrying out the mix design as per IS 456, IS 19262, IRC: 44-2008 and MORTH guidelines. These fibers were inserted to strengthen the concrete, reduce shrinkage cracking, and provide reinforcement across cracks. The quantity of various ingredients required per cum of concrete for achieving 0.39 water cement ratio has been given in Table VI shows material requirements per cubic meter of concrete.

TABLE VI. Material requirement per cum of concrete

Sr. No.	Material	%	By Weight (kg)	Quantity (kg/ m^3)
1	Cement (43 grade OPC)	–	50	425
2	Coarse aggregate			
	(a) 20mm	30	75	598
	(b) 10 mm	25	62	499
3	Fine Aggregate			
	(a) River Sand	23	57	459
	(b) Crushed sand	22	55	439
4	Polypropylene Fibre	–	0.225	1.80

VI. Joints and Other Details

In case of UTW, contraction joint, expansion joint, construction joint and longitudinal joints are provided with slight modification from conventional rigid pavement because of small size panel and bonding of UTW layer with subbase layer. Pavement is divided into relatively short panels by contraction joints which are so spaced to prevent formation of intermediate cracks. No expansion joints are required in case of UTW, however at every 15 m length, a wooden board of width 10mm may be used as construction butt joint with 3 tie bars of 10mm diameter and of length 300mm at spacing of 30cm c/c in each panel with maximum joint spacing of 1.0m. Timely joint cutting (within 6-18 hours of placing of UTW) prevent cracking, minimize curling and warping stresses. An approved high quality sealant shall be used to seal joint reservoirs and prevent moisture and incompressible infiltration into overlay system [4].

Runner beam of concrete grade M 40 without any reinforcement may be provided. For drainage consideration in the longitudinal direction, normal concrete curb stone of grade M 35 may be provided along the length of the beam at a height of 25-30cm above the top level of UTW generally as water table for drainage [4].

Conclusions

Ultra-Thin Whitetopping overlay has been laid on existing distressed HMA pavement for the cluster of roads in Dahanukar colony, Pune, M.S. (India) as rehabilitation option. UTW overlay has been considered as best alternative in this case because these roads are subjected to moderate flow of traffic, having sound substrate of the HMA and located at the bottom of a hill due to which HMA surface in this area used to get washed away in every rainy season and need resurfacing frequently. Following conclusions can be drawn from the literature review carried out during this study and the experience gained during the planning of this UTW overlay:

- UTW is used for airports; interstate, primary and secondary highways; local roads and streets; and parking lots to improve the performance, durability, and riding quality of deteriorated flexible pavement surfaces. Intersections with severe bituminous concrete rutting, or related distresses, can be successfully rehabilitated with an ultra-thin whitetopping.
- IRC: 58 – 2002 and IRC: SP: 76 – 2008 are more realistic design guidelines than any other guidelines for Indian and traffic and climatic conditions.
- UTW is an alternative that restores safety to the roadway, has a competitive cost, and creates minimum traffic disruption. Timely construction and proper staging of the project can minimize delay and burden to the facility users.
- Fiber addition to the concrete mix enhanced durability of UTW overlay. It did not retard cracking and enhanced integrity across cracks.
- Joint spacing should be 10-12 times the UTW thickness to prevent slab cracking due to curling stresses.

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International experience on whitetopping is encouraging. Countries like France, Belgium, U.S.A., U.K. etc. have successfully designed and constructed whitetopping and their performance is satisfactory. But for the country like India this is an upcoming technology, therefore it is necessary to construct few trial sections using indigenous materials and techniques. Carrying out long term performance evaluation of the same is necessary to develop this technique for Indian traffic and climatic conditions.

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